Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
11 (2007) 951–963
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Wind electricity in Denmark: A survey of policies, their effectiveness and factors motivating their introduction

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Received 1 July 2005; accepted 6 July 2005

Abstract

This paper surveys the development of the policies supporting the introduction of wind electricity in Denmark in the last 15 years, with special attention to the new policy introduced after a 2-year long debate. The aim of this paper is to explore the roles of financial support, policy certainty and planning constraints in the diffusion of wind electricity in Denmark and the reasons prompting the change of the system in the current decade. It is discovered that political uncertainty has badly affected the effectiveness of the feed-in law in the years immediately after its introduction. With regard to the new system, it is concluded that the change has been prompted by generous conditions under the feed-in law and by the desire to facilitate the modernisation of old turbines. It is also concluded that incentive-based systems can be more effective than tradable quotas in promoting the modernisation of renewable plants. This finding is relevant to the development of energy policy in countries such as Germany and Spain, where the average age of wind turbines is much younger than those existing in Denmark.

Keywords: Wind electricity; Renewable electricity; Feed-in law

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1364-0321/$ - see front matter
doi:10.1016/j.rser.2005.07.004

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1. Introduction

Renewable electricity has played an important role in Denmark since the first oil shock. Similarly to other European countries, in the late 1970s and in the 1980s the promotion of renewable energy technologies in Denmark was motivated by security of supply. Only in the 1990s after Energy 2000 was published, sustainability and in particularly reduction of CO_2 emissions were added to the agenda. The following plan, Energy 21, fixed targets for the diffusion of renewable energy and the reduction of CO_2 emissions. More details on Energy 21 can be found in [1–3]. The policies for renewable electricity have also been influenced by the 1999 Energy Market Reform, which introduced market competition in the retail and generation markets. As part of the reform, several measures were introduced: the Electricity Supply Act, a new support system for renewable energy generators and a CO_2 quota for electricity producers.[1] Other important changes introduced in the same year were the gas reform, the heat supply act, the energy saving act and the green tax package. Overall, the Energy Market Reform represented a dramatic change for renewable generators because of the decision to replace the subsidy scheme with a certificate-based system. According to official documents, the reform was to ensure a stable demand for renewable electricity whilst increasing competition among generators [1,4].

After surveying the Danish policies introduced in order to increase the share of wind in the electricity system (Sections 2 and 3), this paper discusses the reasons prompting the introduction of the feed-in tariffs and its recent amendment (Section 4). It is discovered that although the level of support for wind has been important, the certainty of the policy has clearly influenced its effectiveness. In addition, the recent changes to the feed-in testify a commitment of the government to increasing the technological efficiency of the wind sector.

2. The early system

Quantitative targets, normally in the form of an agreement between the government and the two biggest utilities, have played a role in the diffusion of wind electricity. The first

[1] The reform introduced the EU Electricity Directive into the Danish legislation and set the framework to protect consumers, environment and security of supply in a liberalised electricity market. For more details of the reform and follow-up legislation see [3].

target is found in Energy 81: 60,000 windmills to supply 10% of electricity by 2000. Although the production share was achieved about 2 years in advance of the target, the number of turbines was under 5000 in 1997 [5]. It is worth noting that the increased average size of turbines had not been forecast by legislation. Another programme was introduced in 1990 to build 100 MW of wind [6], while in 1996 the government and utilities signed an agreement for the installation of 200 MW. Utilities were also responsible for a target of 1500 MW by 2005. However, at the end of 2000 almost 2300 MW had already been installed. In 1998 utilities signed another agreement to install 750 MW offshore wind turbines before 2008. According to the government's forecast, these turbines would generate 10% of the electricity consumption. The agreement is considered the first phase of a total 4000 MW before 2030 [7]. While the presence of quantitative targets has certainly provided a degree of certainty to the Danish wind industry, it would have been impossible to achieve the high levels of generation and installed capacity without the investment and production incentive surveyed below.

2.1. Investment incentives

Investment incentives have been important in Denmark both to promote research on the next vintage of technologies and to increase the adoption of the current vintage. In the case of wind, since 1979 citizens who installed wind turbines were reimbursed 30% of the investment. However, during the 1980s the incentive was diminished to 10% and eventually abolished in 1989 after about 37.6 Million Euros were being granted (280 million DKK) [8].

Research in the wind sector has been funded by the Energy Research Programme.[2] In the 2001 round, about 1.6 Million Euros (12 Million DKK) were given for research on new turbines [2]. New design of wind turbines was also supported in the 1998 round of the Development and Diffusion Programme[3] for Renewable Energy. As new turbines were considered a demonstration project, they were granted between 20 and 40% of the cost. Funding was also provided to test stations and to centres to disseminate knowledge, information and advice [2,3,9]. Privately owned offshore wind turbines were funded under the Development of New Renewable Energy Technologies, which was established in 1997.[4]

Grants for the replacement (i.e. repowering) of old wind turbines under 100 kW were introduced as part of the 1999 electricity reform. Owners of old turbines were entitled to buy shares of electricity, corresponding to triple of the production from their turbines, in new jointly owned wind plants. The owners were also given a fixed tariff of 0.08 (0.60 DKK/kW h) for 12,000 full-load hours. After this, the turbines were treated similarly to new wind turbines—see Tables 2 and 3 [9,10]. According to [2], the project has not been very successful as the procedure for siting new turbines ran into difficulties with local governments.

[2]Projects are normally funded for about 50% of the investment, although the maximum allowed level is 100%. In 1998 42% of the funding was given to renewable projects. The budget in 1997–1999 ranged between 15 and 17.5 Million Euros (about 111-130 Million DKK) [9].

[3]This programme, established in 1992, provides investment grants to demonstration projects, pre-commercial and commercial technologies. Across time the level of subsidies has been adjusted according to the price competitiveness of technologies and it is supposed to cease when a technology becomes price competitive.

[4]The development and testing of wave power, seasonal heat storage from solar energy and hydrogen technology was also funded. The funding for 1997–2000 was 13.1 Million Euros (100 Million DKK).

2.2. Direct taxation and generation incentives

Income arising from privately-owned wind turbines enjoyed favourable taxation until 1996 but since then it has been treated like that originating from any other commercial activity. Before the electricity market reform, utilities were not subjected to taxation, as they were not supposed to generate any profit. After the reform, profit originating from utility-owned turbines has been taxed at the standard rate. According to Haas [11], income tax rules have favoured family investment in wind power as tax deductions were offered until a certain production threshold.[5]

Generation Incentives for renewable electricity dating back to 1979 stimulated interest from cooperatives and private investors in wind turbines, although utilities were typically reluctant. When in 1984 the parliament wanted to pass legislation favourable to turbine owners, the utilities negotiated a 10-year 'voluntary' agreement. Wind generators received feed-in rates amounting to 70–85% of retail electricity price and a contribution to the connection costs. In addition, turbine owners received a substantial incentive in the form of a government tax refund [12] quoted by Lauber [13]. In 1990, disagreement between utilities and generators arose over conditions for grid connections [8]. For this reason at the end of 1992, the great majority of the Danish parliament passed a feed-in law. Energy utilities were to accept renewable electricity, pay a tariff and sustain grid reinforcement costs. Generators were to pay connection costs to the grid but were entitled to receive two generation incentives from the government: the reimbursement of the CO_2 tax, the so-called '10-oeren[6] subsidy' (1.3 €c/kW h) and a production incentive, the so-called '17- oeren subsidy' (2.3 €c/kW h). Plants owned by electricity utilities were not entitled to receive the latter. In addition, electricity from onshore wind received a tariff, i.e. 85% of the retail electricity price, from utilities.

3. The reform of the system

In March 1999, the main political parties struck an agreement to introduce a green certificate system based on an obligation to buy a certain share of electricity from renewable sources. The agreement implied a 66% reduction of the energy budget to about 40 Million Euros (300 million DKK) per year [10]. Savings in the budget were mainly due to the cuts in the production incentive mentioned above and in the CHP fund.

Windmills built after the end of 2002 would sell electricity on the market and receive incentives in the form of a green certificate. A transitional scheme for existing and 'recent mills'[7] was set up to protect those who invested on the basis of the old framework. The details of the scheme for existing, recent and new mills are described in Table 2. As a further protection for investors, if the transitional scheme did not allow them to pay back loans taken before the reform, the companies responsible for the national grid had to take

[5]As long as the number of shares owned by a family corresponded to the family's own electricity consumption, there has been no tax on the shares. In addition, individuals who participate in wind energy co-operatives can own up to 20,000 kW h/year-worth of shares in the co-operatives, of which the first DKK 3000/yr of income is tax-free (and the remainder taxed at a 60% rate) [11] (p. 25).

[6]One Oer corresponds to one hundredth of a Krone.

[7]Mills purchased before the end of 1999 and with the necessary planning permits were considered existing whilst mills purchased and being granted planning permission between January 2000 and December 2002 were considered recent.

over the turbines and the outstanding debt. The Danish Wind Industry Association was moderately satisfied about the outcome of the negotiations. According to its President, although "turbine manufacturers faced radically changed market conditions [...] things did not look too good in the spring of 1999", i.e. at the beginning of the negotiations. At the end the Danish wind industry "seem[ed] to have landed on [its own] feet" [14].

According to the reform, Danish consumers had an obligation to buy 20% of the electricity consumption from renewable sources by 2003. A green certificate system was to cover the difference between the obligation and the capacity under the transitional agreements.[8] The price of the certificates was to vary between a legal minimum of 1.3 €c/kW h (0.10 DKK/kW h) and a maximum of 3.6 €c/kW h (0.27 DKK/kW h), i.e. the fine imposed for non-compliance.

According to the reform, certificates were to be introduced in January 2000. However, in December 1999, it became clear that preparations were not anywhere near completion.[9] When the Danish Wind Industry Association and the Danish Wind Turbine Owners Association demanded a postponement to prepare for the change, the Energy Minister accepted this request and in March 2000 it was announced that the system would start in January 2002 [14]. However, preparations for the implementation were somewhat slow[10] and the scheme was again postponed to January 2003. Eventually, in June 2002 the Minister for the Environment and Energy shelved the plans for the certificate scheme and a 1.3 €c/kW h (0.10 DKK/kW h) premium rate was introduced for a maximum length of 20 years. The rates are shown in Table 3. A scrap premium was also introduced granting an extra 2.3 €c/kW h (0.17 DKR/kW h) for new onshore turbines built before 2004 if the owner demolished an old and obsolete windmill. Finally, in the latest amendment to the electricity supply act, not yet in force, the scrap premium was extended until 2009 although at the reduced rate of 1.6 V c/kW h (0.12 DKR/kW h). Considering the market price, this implies that electricity from new onshore turbines will be paid a maximum of 6.5 €c/kW h (0.48 DKR/kW h) [16].

4. Effect of the Danish policies

The increased use of renewable electricity in Denmark has been mainly due to the diffusion of wind; in 2001 the capacity of all other sources was barely one-tenth of the installed windmills [15]. Although the cumulative capacity has increased each year since records began, the diffusion of wind has been neither a constant nor a non-linearly monotonous process. As shown in Fig. 1, the additional generating capacity presents a rather unstable behaviour.

One can assume that the decision to invest in wind turbines depends on the stream of future costs and revenues. Hence, an investment should go ahead if and only if the Net

[8] Only 3 TW h out of nine were expected to take part to the certificate system in the first couple of years. Since then the production outside this scheme should have decreased in 2012 [4].

[9] According to Lauber [13], "no one really knew how certificate trading would function. Nor was it clear what this would mean in terms of transaction costs, especially for small units" (p. 10).

[10] For example, in September 2001, it was not yet clear whether the system would comprise technological bands or not.

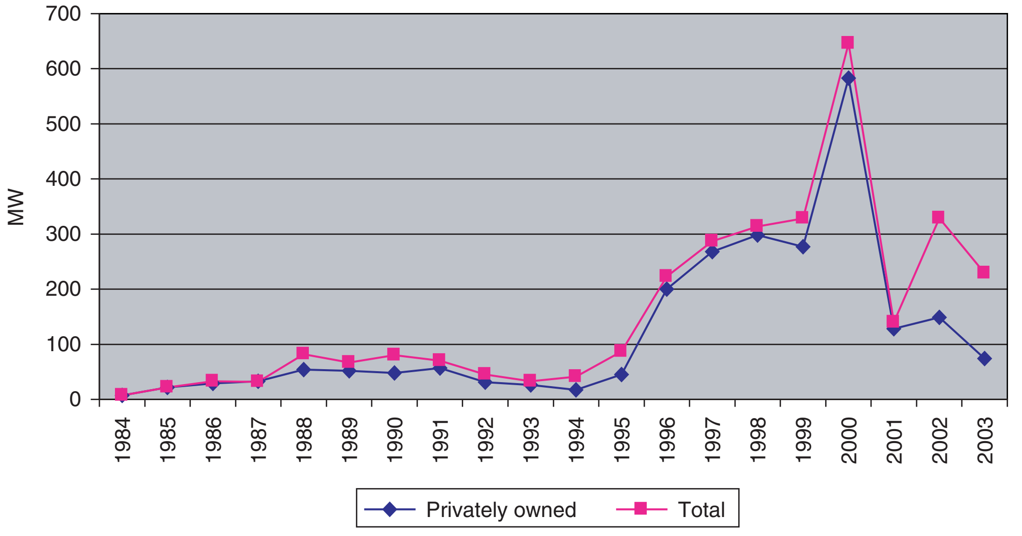


Fig. 1. Wind additional generating capacity. *Source*: [18].

Present Value (NPV) is bigger than zero

$$\mathrm{NPV} = \sum_{i=1}^{n} \frac{(B_i - C_i)}{(1+r)^i} > 0 \quad (1)$$

where B represents the benefits from the investment, C its costs and r the interest rate. In the case of a wind plant in Denmark, the benefits from the investment correspond to the sum of the generation incentives and electricity revenues while the costs are related to the generation of electricity. Benefits and costs have to be summed over the expected life of the investment (n), as pointed out by the index i above. As benefits and costs are normally uncertain, the figures in Eq. (1) are in expected terms.

It can be assumed that investors thought generating costs would decrease over time. This is indeed what happened in Denmark (see Fig. 2) and in other European countries, due to the increased size of turbines and technological progress [10,11]. Similarly, benefits were also easy to forecast as they were fixed[11] by the Feed-in law—see Table 1. Given Privately owned Total these features of costs and benefits, market penetration of wind electricity should not show the instable behaviour in Fig. 1.

4.1. The introduction of the feed-in tariff

Fig. 1 shows that in 1992, when the feed-in law was passed, additional wind capacity decreased from its pre feed-in levels. The absence of an immediate take-off after the introduction of the feed-in law can be explained by the expectations on the stability of the policy. Investors were probably influenced by the so-called hold-up problem [17], which arises when two or more parties, e.g. the government, a utility and a wind generator, can

[11]The tariffs were not constant across time as they were related to the retail electricity price. However, this has shown a slightly upward trend responsible for only a marginal change in the tariff.

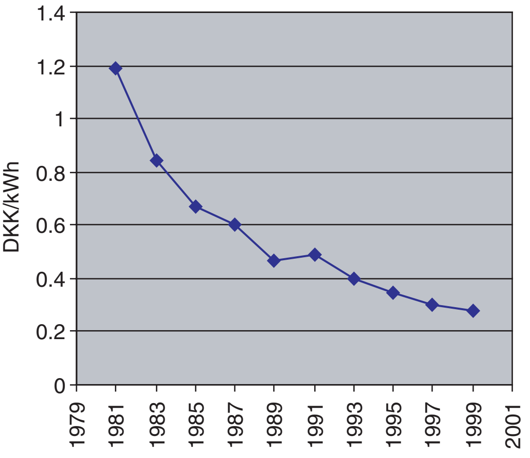


Fig. 2. Estimated generation costs of wind energy in Denmark. The calculation is based on a 20-year long depreciation period and on a 5% interest rate. *Source*: [7] p. 11.

Table 1
Average price paid to electricity from wind, biomass and PV

Tariff	CO_2 tax refund	Production incentive	Total	Average
3.36–5.24 € c (0.25–0.39 DKK)	1.3 €c (0.10 DKK)	2.3 € c (0.17 DKK)	6.96–8.84 €c (0.52–0.66 DKK)	8.1 € c (0.60 DKK)

make a profit after one makes an investment, e.g. a wind turbine. The hold-up problem is related to the fact that after one party invests, the others have the power to demand a larger share of the profits than that fixed in the agreement. In other words, after a party invests the others gain some bargaining power.

The extent of this problem depends on the specificity of the investment, i.e. the drop in the investment value when the agreement breaks down. Needless to say, after turbines have been erected, generators do not have many options apart from producing and selling electricity. According to the feed-in law, they could sell only to the utility owning the local grid. Should the relation with the utility break down, a generator would not have any other potential partner. In other words, generators knew from the start that they would have entered a risky agreement. Although the desire to have a good reputation[12] prevents parties from taking advantage of the hold-up problem, this did not apply in Denmark. Danish utilities were not much interested in preserving their reputation as reliable partners, as there had been already an intense degree of confrontation with generators. A previous voluntary agreement between generators and utilities broke down when utilities claimed that generators enjoyed extraordinarily large profits, although this claim was later refuted

[12]The rationale is that the reputation is a long-term asset, which decreases the transaction costs of doing business, e.g. looking for reliable partners. Most economic agents will prefer not to take advantage of short-term gains such those arising in the hold-up problem so as to preserve their reputation.

by a study of the energy ministry [13]. The Danish government introduced the feed-in law when the voluntary agreement became untenable. The government had a stake in both utilities and generators. It wanted the latter to build turbines so as to meet the targets in the energy plans while it wanted the former to be in a sound financial position to deliver electricity to customers. By replacing the voluntary agreement with the feed-in law, the government acknowledged the investors' need for legal certainty. Increasing the certainty of the payments to wind electricity should have raised their expected values, given the nominal ones. As this implies higher net present value, according to Eq. (1), there should have been an increased number of projects going on-line. It is therefore puzzling that the additional generating capacity decreased at the introduction of the feed-in law.

The fact is that the future of the feed-in law and therefore of the tariffs paid to the generators was far from being certain. According to Lauber [13], at the beginning of the scheme, "the Danish utilities dragged their feet on implementing the new law and successfully created an atmosphere of insecurity among potential investors" (p. 301). In fact, while in 1988–1991, the additional wind generating capacity was about 70 MW per year, in 1992–1994 it was about 35 MW [18]. The turning point occurred in 1995–1996 when additional generating capacity bounced back to 80 MW and then jumped beyond 200 MW per year. Lauber [13] imputes this change to the new government (elected in 1993), the merger of the environmental and energy ministries and to the appointment of a minister with views sympathetic to renewable generators. In terms of (1), this implies that generators did not have any reasons to keep the expected values of the benefits much lower than their nominal ones.

Nonetheless, Christensen [16] rejects the view that obstruction by utilities companies played a role in the reduction of additional wind generating capacity observed in 1992–1994.[13] He concludes that this was due to the fact that the "tariffs initially did not live up to the expectations of windmill owners, as the retail electricity price, to which the tariffs were linked, did not rise as much as expected". Although this factor undoubtedly influenced the decision to invest, it is improbable that it can explain on its own the substantial decrease that occurred in those years. The feed-in tariffs were in fact at least as high as the rates paid by utilities under the previous voluntary agreement.[14] Hence, after the introduction of the feed-in law additional generating capacity should have kept increasing at least at the same pace of the previous years. Furthermore, as in the last part of the decade the electricity price and hence the tariffs increased only slightly, this factor on its own cannot explain the change observed in the additional capacity after 1995.[15] Holst [22] points out at increased planning constraints in the first part of the 1990s. Later, a new planning regime mandated local governments to indicate zones for windmills and made the siting of turbines much easier. Although planning constraints are likely to have contributed to the slow-down in the additional capacity, it seems likely that the uncertainty surrounding the introduction of the feed-in law is the main factor responsible for the 50%

[13]The time of obstruction by the electricity companies was before 1992, when feed in conditions solely depended on an agreement between wind mill owners and the companies [16].

[14]In the voluntary agreement wind generators received 70–85% of the retail electricity price while the tariff in the feed-in law corresponded to 85% of the retail electricity price, see Section 2.

[15]Christensen [16] mentions that at the beginning of 1997 there was a change to the rules on ownership of windmills so that individuals or associations of owners might have several windmills or shares in windmills. The author acknowledges that this could have helped the increase in 1997. However, this does not explain the rebound in 1995 and the substantial increase in 1996.

decrease of additional wind capacity in 1992–1994 compared to levels observed in 1988–1991.

4.2. The reform of the system

As it is sometimes pointed out in the literature the feed-in law became victim of its own success. When in 1998 the amount of production incentives surpassed 90 Million Euros (about 703 Million Krones)—86% paid to windmills—it became clear that the long-term financial feasibility of the system was compromised [10,16]. It is worth pointing out that another cost of the policy consisted of the amount of CO_2 tax reimbursed to renewable generators. In addition, the government was also worried about the financial position of utilities. Due to the imminent market liberalisation, improving the utilities' efficiency and their financial position was an important issue, which became even more urgent when the electricity price drastically fell in the summer of 1999. As the utilities were transformed into private companies from their then status of non-profit organisations, the government wanted to achieve a more efficient use of capital in these enterprises [19] so that they could effectively compete in the new electricity market. According to the original plans, the future increase in renewable electricity was to be financed by the general public through the green certificates and by the market through the purchase of electricity. The role of the tariffs paid by utilities and of the incentives paid by the government was over. As a consequence of the reform, production incentives were to be reduced by about 88% [10]. The reasons mentioned above do not justify on their own a change of the instrument. If the problem was the amount of money paid by government and utilities, one could have passed these costs directly to consumers without swallowing the energy budget or compromising the financial position of utilities. The mechanism introduced in the German Renewable Energy Act or that adopted in England and Wales to fund the Non Fossil Fuel Obligations are two clear examples. If the aim was to expose renewable generators to the competition of the market, one can have abolished the feed-in tariffs but kept the generation incentives. Another explanation for the change of the feed-in tariff to a green certificate scheme is perhaps the Renewable Electricity directive, then under preparation in Brussels. At that time the European Commission had a strong preference for Tradable Certificates and was threatening to initiate a review procedure of the German feed-in law on the basis that it constituted a state aid. Very likely the Danish government wished to avoid being the next to attract the attention of the European Commission. At the same time it perhaps wanted to anticipate the introduction of the instrument likely to be proposed by the commission. By doing so the Danish wind sector would have gained experience, which could have been used—and turned into money—when the green certificates would be traded across borders.[16]

As it can be seen from Table 2, according to the proposal the tariffs paid to the mills 'erected' by December 1999 received much better conditions that those commissioned afterwards. This caused the surge in additional generating observed in 2000—see Fig. 1—as investors hurried to gather legal permits (ca. 500) before the end in 1999 although most of the turbines were actually built in 2000 [16]. However, in 2001 investors did not show much interest in the wind market due to the protracted uncertainty of the future of the

[16]This was one of the motivations prompting the British government to introduce the UK Emission Trading Scheme before the start of the European policy [20].

Table 2
Transitional and long-term payment for wind according to the proposal

	Transitional		Long-term	
	Tariff	Incentives	Green certificates	Electricity price
Existing mills[a]	4.4 € c[b] (0.33 DDK)	3.6 € c[c] (0.27 DDK)	1.3–3.6 € c[d] (0.10–0.27 DKK)	Paid to the generator[e]
Recent mills[f]	4.4 € c[g] (0.33 DDK)	1.3 € c[c] (0.10 DKK)	1.3–3.6 € c[d] (0.10–0.27 DKK)	Paid to the generator[e]
New mills[h]			1.3−3.6 € c (0.10–0.27 DKK)	Paid to the generator[e]

All rates are per kW h. *Source*: [10] (p. 22).
[a]Turbines purchased before the end of 1999 and with the necessary planning permits.
[b]Until the turbine is 10 years old or until December 2002.
[c]Up to a maximum of 25,000 full-load hours (the amount of full-load hours depends on the capacity of the mill. In particular it was set at 25,000 for turbines below 200 kW, 15,000 for those between 201 and 599 kW and at 12,000 for those larger than 600 kW).
[d]After 10 years.
[e]After the end of incentives.
[f]Turbines either purchased or being granted a planning permit between January 2000 and December 2002.
[g]Until the mill is 10 years old.
[h]Built after January 2003.

green certificates and to the reduced level of incentives. It is also thought that protests somewhat limited the number of sites available [16]. By the time the scheme was postponed for the second time in September 2001 several political parties, which previously supported the policy, had in the meantime changed sides.

The scheme had in fact lost much of his appeal. After the advocate general and the EU Court of Justice suggested that feed-in laws were compatible with the EU legislation (October 2000 and March 2001) and after it was clear that green certificates would not be traded across Europe in the near future, there was not really a reason for the Danish government to stick to this instrument. In the meantime orders forwind turbines in the Danishmarket brought about a near-collapse of the domestic industry [13]. At the end the scheme was indefinitely put on hold in June 2002. The Danish press acknowledged this as a "victory for the large Danish wind turbine factories who have consistently been against this very complex renewable energy market" [21]. Due to the importance and size of the wind industry in Denmark, it can be noticed that in addition to lobbying organisations with an obvious stake into renewable electricity,[17] the Confederation of Danish Industry was also against the reform.

The abandonment of the green certificate scheme has been an important step in the Danish policy. While on the one hand the new incentive-based system decreased the revenues paid to windmills (as shown in Tables 2 and 3, the premium rate is in fact charged at the minimum of the price range of green certificates), the new policy signals a change going beyond the financial conditions of windmills. Due to the fact that Denmark started installing turbines very early, about half the windmills are 10–25 years old and have a much smaller size than the new turbines [22]. As onshore sites are becoming a scarce resource, the way forward is to 'repower' old turbines. This is the main message from the

[17]Namely, the Danish Wind Turbine Owners' Association, the Danish Agriculture's Energy Committee, the Danish Wind Industry Association and the Organisation for Renewable Energy.

Table 3
Payment to wind turbines and biomass plants according to the amendments of the transitional arrangements

	First 10 years		Second 10 years	
	Tariff	Incentives	Premium rate	Electricity price
Existing mills[a]	4.4 € c (0.33 DKK)	3.6 € c (0.27 DKK)	1.3 € c (0.10 DKK)	Paid to the generator
Recent mills[b]	4.4 € c (0.33 DKK)	1.3 € c (0.10 DKK)	1.3 € c (0.10 DKK)	Paid to the generator

	Twenty years		
	Scrap premium	Premium rate	Electricity price
New mills[c]		1.3 € c (0.10 DKK)	Paid to the generator
Repowered mills[d]	2.3 € c (0.17 DKK)	1.3 € c (0.10 DKK)	Paid to the generator
Repowered mills[e]	1.6 € c (0.12 DKK)	1.3 € c (0.10 DKK)	Paid to the generator

[a]Turbines connected to the grid before Jan 2000.
[b]Turbines connected to the grid in 2000–2002; for the following 10 years.
[c]Turbines after January 2003.
[d]For turbines repowered before January 2004.
[e]For turbines repowered before January 2009.

new policy. As the 'scrap premium' and the 'premium rate' in the reformed system add up exactly to the maximum price of green certificates—see Table 2—one can conclude that the Danish government has not backed off from its support of the wind sector but is simply leading it to a more efficient and technologically advanced state. As most of the additional generating onshore wind capacity in 2002 was due to repowering [18], investors seemed to go along the policy direction pursued by the government. This would have been much more difficult in a green certificate system, unless one was ready to decrease the liquidity of the market or the development of renewable capacity. In fact, a green certificate system can explicitly promote the repowering of old installations only if certificates are divided according to the age of the plant or if the current production exceeds the quota prescribed by the law. If certificates are divided according to the age of the turbines, the government could decrease the share of the certificates for old turbines, thereby increasing incentives for generators to repower their installations. In any case when the share of renewable electricity prescribed by the law is not fulfilled, generators are able to sell their certificates at the maximum price fixed in the scheme, as there is no competition in the market. Under this scenario, it is unlikely that most investors would be ready to replace their old installations with new turbines, as the former provide them a positive return at no risk. The effect of green certificate systems in countries with old plants and a high renewable electricity share should be considered when discussing the merits of feed-in tariffs versus tradable quotas.

5. Conclusions

Considering the decision to invest in a certain technology, this paper has shown that the uncertainty of financial incentives incorporated in the feed-in law influenced the deployment of windmills in the years immediately after the introduction of the policy.

Although planning constraints and the price risk of the tariffs have been also important, only the regulatory risk can fully explain the slow-down in additional wind generating capacity observed in 1991–1994. In fact, regulatory risk decreases the expected value of the tariffs and therefore the number of projects with a positive net present value. The author does not see any reason preventing the extension of this result to the deployment of other technologies in other countries. This paper also pointed out that the reform of the Danish system has been influenced by the financial sustainability of the previous policy, the debate around the European Directive on Renewable Electricity and by the relatively dated turbines in place in Denmark. As an incentive-based system such as that introduced in Denmark is more likely to promote the modernization of old turbines than a green certificate system, one can conclude that the Danish government has chosen the right instrument to stimulate the technological and economic efficiency of the wind sector.

Acknowledgements

The author would like to thank Paul Ekins from the Policy Studies Institute for discussing previous drafts of this paper and Holger Christensen from the Danish Energy Authority and Jakob Lau Holst from the Danish Wind Industry Association for helping his understanding of the Danish policies. The paper has drawn upon work completed for Tyndall Centre project T2.12—ETech+: Technology policy and technical change, a dynamic global and UK approach. Discussion with colleagues on this project is also gratefully acknowledged.

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